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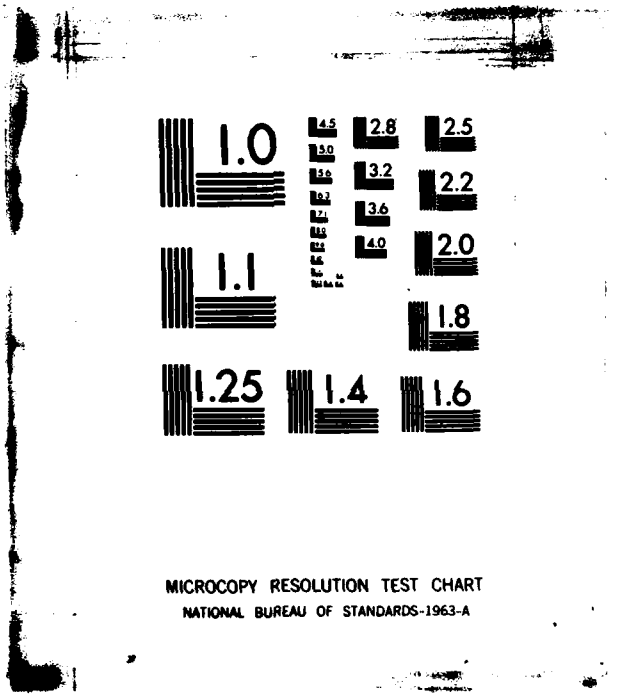

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AUTONOMOUS COMPUTER CONTROLLED ICE DRILL

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Abstract

An unmanned autonomous system, designed ultimately for air deployment, has been developed for drilling holes in the Arctic ice. The system is intended to facilitate the collection of oceanographic data in inaccessible regions of the Arctic as part of the Air Deployed Oceanographic Mooring (ADOM) program.

This paper describes the design of the drill, the microcomputer control system, and the results of initial field testing.

1. Introduction

The collection of oceanographic data in the remote areas of the ice covered Arctic has been extremely costly and often dangerous. With the availability of satellites for data relay, and microcomputers for system control and data formatting, an automated airdropped ice drill became feasible. In order to pass a typical instrumentation package a hole is required of at least six inches (15 cm) in diameter, running the full thickness of the ice cover.

Extensive study [1] of the statistics of the ice thickness indicated that 99% of Arctic ice was less than 50 ft (15.25 m) thick. The drill was thus designed to drill through 35 to 50 feet of sea ice. Note is made that the ice is not necessarily homogeneous, and melt water may leak away. Freezing of the hole after drilling is acceptable.

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

An unmanned autonomous system, designed ultimately for air deployment, has been developed for drilling holes in the Arctic ice. The system is intended to facilitate the collection of oceanographic data in inaccessible regions of the Arctic as part of the Air Deployed Oceanographic Mooring (ADOM) program. This paper describes the design of the drill, the microcomputer control system, and the results of initial field testing.

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A variety of drilling methods were examined [2], resulting in a choice of thermal melting, driven by battery power, as the most reliable means that is subject to automatic control. The energy required to melt a 50 foot column of -25°C ice 6 inches in diameter is 26.2 kWh. This implies that a total energy supply of 30 kWh would be required for a fully operational drill, given nominal efficiencies and reserves. Such energy is available today in reasonable physical packages.

2. The Drill Concept

To achieve efficiency the thermal drill should run as cold as possible; quite unlike the intuitive perception which would look to high temperatures to melt the ice rapidly. We seek the highest heat transfer coefficient possible, approached here by turbulent flow, in order to achieve a maximum exchange of energy. Efficiency is important since all the energy for drilling must be transported to the site, and the electrical batteries used for the drill can be expensive.

The distance between the nozzle and the melt water intake port is appreciable; 40 inches in the current model. The drilling is initiated by employing a conventional hot point technique, where the end of the drill is elevated in temperature to about 95°C. When penetration reaches the ports, the jet pump is primed, and the automatic control initiates jet drilling.

Figure 1 illustrates the drill. The parabolic hot point contains 9 cartridge heaters, each rated at 781 watts at 300 volts, plus 3 thermistors for control. The heaters are connected in groups of 3 for ease in temperature control. A hole of 5/8

inch diameter (1.59 cm) is placed in the center of the hot point for the jet stream.

The 21 inch long (53.3 cm) water heating chamber, with a cross section of 3.75 x 3.25 in (9.53 x 8.26 cm) contains 20 cartridge heaters, in a radial configuration, which are wired as 4 banks. Each is rated at 625 watts for 3.1 kW per bank and 12.5 kW total. Eight heaters are equipped with control thermistor probes.

Located above the heaters is a 3 stage 1.5 hp centrifugal pump, driven by a 240 V AC motor. In the compartment above the pump is the microcomputer controller, the power control switches, and the fuse block.

The power cable serves as a strength member for deploying the drill as it proceeds through the ice. It supplies 300 volts at 42 amps. maximum for heaters, 6 volts for the computer, 240 volts AC for the motor, and a communication line. The capsule that remains on the surface of the ice after the operation is completed contains the satellite communication system, the computer for formatting the sensor data, the battery supply, and the inverter to generate the AC power for the motor.

3. Drill Operation

The drill is guided by gravity (pendulum stabilized), relying on its low center of gravity, high center of bouyancy and cable tension for near vertical drilling. The dry weight of 100 pounds (45 kg) in the initialization phase maintains good thermal contact between the hot point and the ice. A counter force

slightly less than the wet weight of the drill (67 lbs, 30 kg) is applied to the cable.

On initiation of drilling the computer turns on the hot point heater banks sequentially. The probes are monitored to maintain hot point temperature below the boiling point. Drilling proceeds no faster when boiling and the additional energy of boiling is wasted. As the drilling proceeds to a depth of some 40 inches (1.01 m) melt water primes the pump, actuates a sensor and the jet drilling proceeds.

In the jet phase the pump is turned on, the hot point deactivated, and the power applied to the heater banks in the water heating chamber. Water, at a rate of 40 gallons per minute, is forced past the heaters, now elevated only a few degrees, and jetted out the nozzle. The passage of the water along the outside of the drill causes the hole to be enlarged to its design dimension.

Drilling is completed when the system breaks through to the sea beneath. It then serves as a weight to pull as much as 1000 meters of instrumentation cable through the hole.

4. The Control System

The energy involved in this drill is sufficient to cause catastrophic damage. If melt water were to disappear due to a fissure in the ice, the heaters would immediately rise to damaging temperatures. A shorted cartridge could be destructive. A pump failure would initiate serious damage. In all cases of potential component failure, alternative strategies have been established in the system to minimize the effect of subsystem

failure. In addition to assuring reliability, effective control will conserve power by efficiently employing it as needed.

A microcomputer, using CMOS components, and employing an IM-6100 microprocessor controls the drill through a bank of solid state switches, employing high power FETs. The program occupies 2400 12 bit words of memory. A sensor that determines if ample melt water is present establishes the transition from hot point to jetting mode. Thermistor sensors then provide the inputs to the computer for drill control.

Concern has been expressed over the reliability of the thermistor sensors in this environment, and the consequences of such failure. The computer constantly checks thermistor operation and is prepared to initiate backup strategies. In the jetting mode eight thermistor in-puts are available; two per heater bank. Comparisons are made within the paired sensors, and also between banks. The heaters normally operate between fixed upper and lower limits. Beyond the upper limit is a cutoff overtemperature limit which can vary depending on comparisons between sensors. If levels are within an acceptable tolerance range, confidence is high and the cutoff temperature is set at the maximum level based on evidence that the sensors are functioning correctly. Disparities in readings, due to heater or to sensor failure, cause the cutoff temperature to be set at a lower more conservative level. If the cutoff temperature is reached all heaters are shut down. Power again cycles on, but if the disparity between sensors remains, cutoff again occurs. In this event the computer masks out, or ignores the two sensors involved and the control of that bank reverts to sensor data from

an alternate heater bank. In the event of all jet heaters failing the control reverts to the hot point mode in an effort to complete the mission. A hardware backup exists that can shut down the heater banks in the event that temperatures rise too rapidly for the software to react.

The hot point control system also has a system for masking out, or dropping, ineffective sensors, similar to that employed in the jetting system.

All heaters are fused individually so that if heaters fail in a short circuit mode, the fuse will protect the remaining heaters in the bank.

The use of an intelligent system permits an adaptive approach to control, allowing for soft failure and alternative strategies that assure high drilling reliability.

It is noted that computers may also fail. A watchdog timer is included that must be reset periodically as one of the routine chores of the computer. If reset does not occur, the computer is shut down and restarted. This cycle is repeated several times on computer failure. It then turns on the hot point system to attempt to complete the mission with open loop control.

5. Performance

The drill has completed initial tests at the U.S. Army Cold Regions Research and Engineering Laboratory, and is scheduled to complete advanced development model tests in the summer of 1982. Initial prototype tests showed an average efficiency of 73.2% defined as a ratio theoretical energy of drilling to actual energy used. 2.35 kWh of energy was required to penetrate one

meter of ice at -25°C. Heat transfer coefficients were very high, up to 1.2 x 10^5 W/m^2°C. Average drilling rate observed in this initial test was 6.8 cm per minute at 9 kW power level. Figure 2 illustrates a profile of the drill operating performance.

We are finding that the recirculating water jet ice drill is an effective and efficient method for drilling holes in the Arctic ice with systems that do not require operator attendance.

Appreciation must be expressed to others in the Marine Systems Engineering Laboratory who have contributed to this development. Recognition is made to Code 421 of the Office of Naval Research for their support and leadership.

6. References

1. Blidberg, D. R., Corell, R. W. and Westneat, A. S., "Probable Ice Thickness of the Arctic Ocean," Coastal Engineering, 5 (1981); 159-169.

2. "Air Deployed Oceanographic Mooring (ADOM) Final Report, March 1, 1978 - February 28, 1979," Marine Systems Engineering Laboratory, University of New Hampshire, Durham, NH.

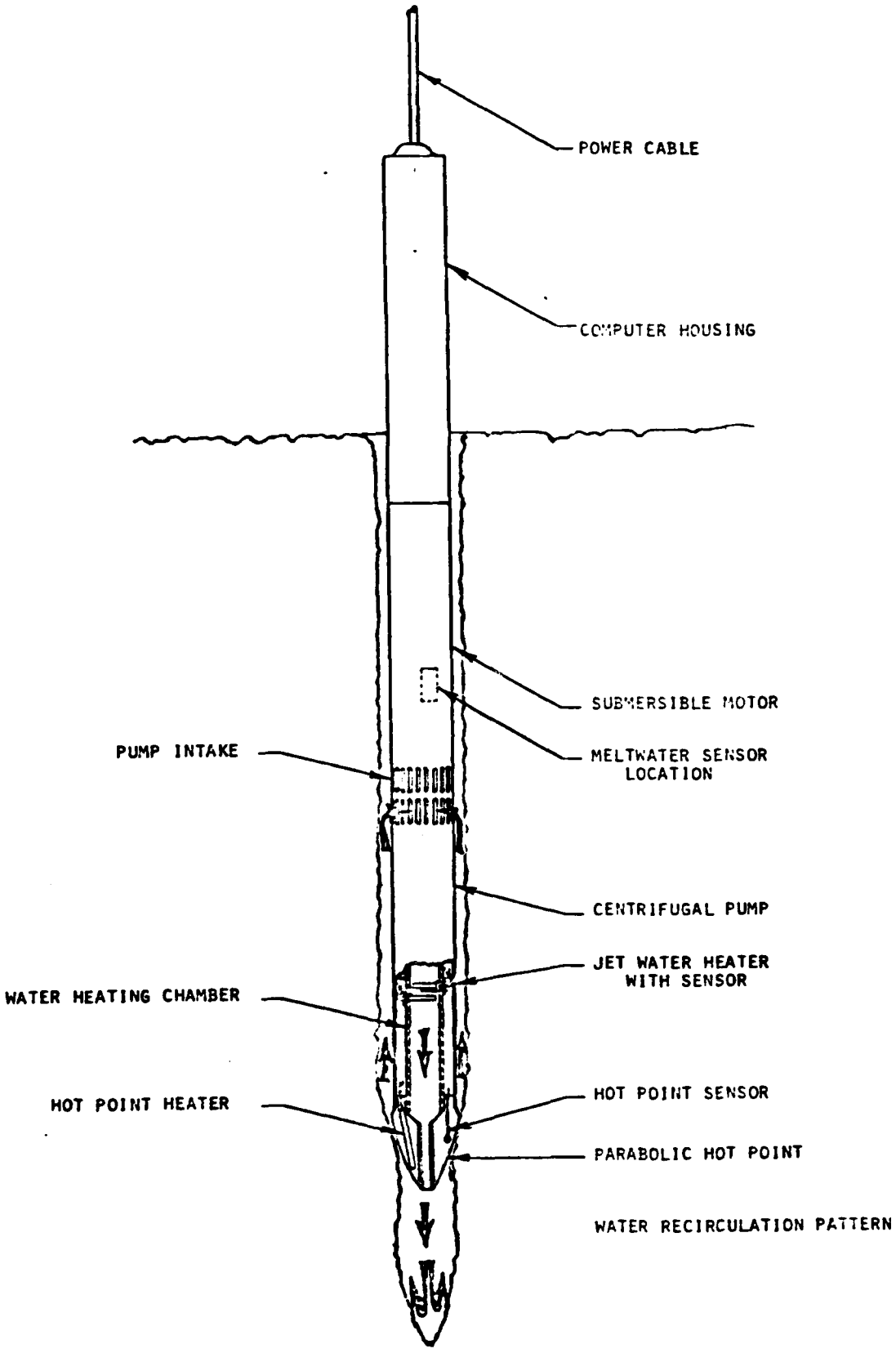
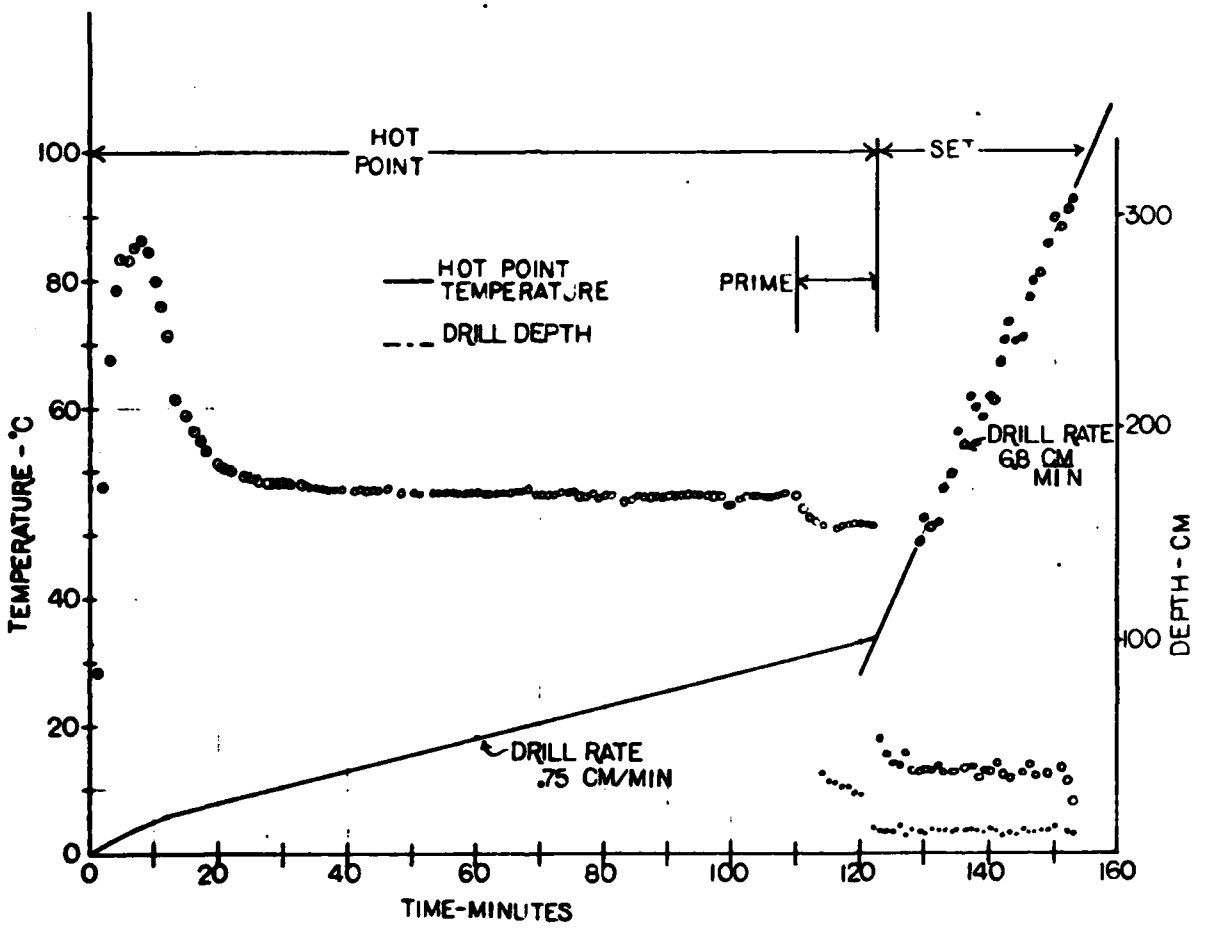


FIG. 1 ADVANCED DESIGN MODEL ICE DRILL



TEST DATE: 4 MARCH 1980
HOT POINT POWER: 12 KW
ICE TEMP: -37°C
NOZZLE DIAMETER: 15.9 MM
TOTAL POWER: 10.1 KW

FIG. 2 TYPICAL DRILL PROFILE

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